Impact of IEEE 802.11 PHY/MAC Strategies on Routing Performance in Wireless Mesh Networks

Chiraz Houaidia, Hanen Idoudi, Adrien van den Bossche, Thierry Val, Leila Azouz Saidane

Impact of IEEE 802.11 PHY/MAC Strategies on Routing Performance in Wireless Mesh Networks

Chiraz Houaidia*§1, Hanen Idoudi*2, Adrien Van Den Bossche§3, Thierry Val§4, Leila Azouz Saidane*5
*Ecole Nationale des Sciences de l'Informatique (ENSI),
Manouba University
Campus Universitaire de la Manouba, Tunisia
1chiraz.houaidia@cristal.rnu.tn, {2hanen.idoudi, 5leila.saidane}@ensi.rnu.tn
§CNRS-IRIT-IRT, Université de Toulouse, UT2,
1 pl. G. Brassens, BP 60073, 31703 Blagnac Cedex, France {4val, 3bossche}@irit.fr

***Abstract*—Current routing mechanisms proposed for adhoc networks are still feasibly applied in Wireless Mesh Networks given their similarities. Many researchers have conducted numerous simulations for comparing the performances of these routing protocols under various conditions and constraints. Most made comparisons are not aware of PHY/MAC layers and their impact on routing performances. In this paper we study through simulations the impact of PHY/MAC protocols on higher layers. The considered protocols include three propagation models, ie., FreeSpace, TwoRayGround and Shadowing, three different PHY/MAC protocols specified IEEE 802.11 standards namely, 802.11b, 802.11s and 802.11n, and finally three routing protocols, ie., AODV, OLSR and HWMP. In a comparative way, we investigate the effectiveness of these protocols when they coexist on a wireless mesh network environment. Our results show that the routing strategy can significantly impact the network performance only if it is strongly linked to the characteristics of the lower layers.**

***Index Terms*—Wireless mesh network, PHY/MAC protocols, Routing protocols.**

I. Introduction

Wireless Mesh Networks are a promising technology to provide broadband wireless Internet to a large number of users spread across large geographical regions. Due to their features of dynamic self-configuration, easy maintenance and low cost, WMNs promise larger coverage, improved performance, more reliability and better flexibility than classical wireless LANs. In fact, in rural areas, where broadband infrastructure is not available, WMNs may be a potential solution to provide these regions with a reliable Internet access based on multihop connections. In this context, the French association tetaneutral.net [19] has launched its project to cover the region of Toulouse in France in a meshed manner. This association is acting as a provider of Internet access, web hosting and a nonprofit operator and is aiming to allow and encourage internet connection sharing between neighbors by any means (cable, wireless, etc.). It offers also a technical solution allowing a secure access share. WMNs have a two-tier architecture based on multi-hop transmission and composed of two types of nodes: Wireless Mesh Routers (WMR) and mesh clients [3]. WMRs form a wireless meshed backbone network offering inter-user connectivity. They generally have minimal or no mobility and are equipped with multiple radio interfaces. Mesh clients, consisting of end devices like laptops, PDAs or phones, gain network access by associating to a WMR. When a mesh client wants to communicate with another, it may do directly or through mesh routers that allow multiple route opportunities.

Mesh networks share some characteristics with ad-hoc networks in the way that both are based on multi-hop communication and both are used to provide broadband access to Internet. Reason for what, current MAC and routing mechanisms can still feasibly applied in WMNs. However, MANETs, evolved from an academic environment, focus essentially on node mobility, power constraint and related ad-hoc capabilities. In contrast, mesh networks, emerging from an industrial background, are focusing more on optimal deployment, wireless capacity, QoS and related backbone capabilities. Indeed, existing MAC and routing protocols do not support enough scalability, throughput and link quality. For these different aspects WMNs are gaining significant attention from both academic and business communities. In fact, researchers and industrial standards groups are revisiting, from a mesh perspective, existing protocols for wireless networking mainly IEEE 802.11 standards and are actively working on new specifications [4].

Routing, particularly, has undergone extensive study since it represents a challenging issue for wireless mesh networks [6][7][8][11]. In fact, in a multi-hop network, routing extends network connectivity to end-users. Thus, an efficient path selection must be done while optimizing network resources and satisfying users QoS requirements. However, with an unstable radio environment, a shared medium and a varying link capacities limited by interference, routing performance issues in a WMN are increasingly challenging. Packet losses, throughput degradation due to intra-flow and inter-flow interference, congestioned links, etc., are among several problems identified in WMNs and issued generally from lower layers. To guarantee then an efficient data routing in the network, one should, first, properly characterize the impact of environmental factors and PHY/MAC attributes on higher layers and second adapt the design of the routing metric to better control influenced parameters.

In this paper, we try to check the efficiency of conventional routing strategies under lower layers and whether the choice of PHY/MAC/Routing protocols all together affects the relative performance of the network. The considered protocols include three propagation models [13], ie., FreeSpace, TwoRayGround and Shadowing, three different PHY/MAC protocols specified IEEE 802.11 standards namely, 802.11b [4], 802.11s [3] and 802.11n [9], and finally three routing protocols, ie., AODV [1], OLSR [2] and HWMP [12]. The remainder of this paper is organized as follows: In section II, we present the routing challenges in wireless mesh networks. The simulation results and analysis appear in Section III. We conclude with Section IV.

II. Routing Challenges in Wireless Mesh Networks

Despite the availability of several ad-hoc routing protocols, the design of routing protocols specifically for WMNs is still an active and challenging research area. In fact, from a routing perspective, WMNs present a particular topology and different application domains and thus specific requirements and expectations. The main challenging considerations in mesh routing are:

- *Network topology*: similarly to MANETs, communication in WMNs is performed through hop-by-hop wireless transmissions. However, unlike MANETs, WMNs offer a static backbone for routing and thus routing protocol should perform an adequate mobility management.
- *Inter-path interference*: unlike wired networks, wireless links in a WMN are particularly affected by environmental conditions, noise resulting in interference between disjoint paths and hidden/exposed terminal problems. For that reason, this parameter should be well addressed in the routing metric.
- *Channel diversity and radio-diversity*: in WMNs, channel diversity, which is not supported in traditional MANETs, is introduced in order to increase the overall throughput and to reduce inter-nodes interference. Providing a node with multiple radios enables it to transmit and receive simultaneously or transmit in multiple channels simultaneously. So, to properly support this feature, additional management rules (like channel switching) should be included into the routing process.
- *Routing strategy*: similarly to ad-hoc networks, routing strategy can be either proactive, reactive or hybrid. The choice depends on the network density, the node mobility, the related overhead and user requirements. Each routing class has its particular functioning such as route discovery, route maintenance and related control messages, acknowledgment strategy, route update frequency etc. Hence, such choice can be determinant in the overall network performance.

When taking into account these parameters, routing protocols should fulfill several requirements, including, (i) High throughput, (ii) Low average latency, (iii) Heterogeneous traffic (e.g. data, voice, and video), and (iv) Support for QoS.

Nevertheless, if we consider a realistic context, it is not meaningful to speak about a routing protocol in isolation. Routing performance is considerably related to MAC and PHY layer design. To have an efficient routing layer, an overall view of the MAC and PHY parameters should be provided in order to control lower layers settings and discuss possible improvements. Some solutions based on cross-layer approach are proposed to deal with this separation between layers [14][15].

III. Performance Evaluation

In this section, we propose to evaluate the netwrok performances under different PHY/MAC/Routing strategies and parameters. In a comparative way, we try to test the possible interaction and coexitence of some protocols in a wireless mesh environment and how does this impact the network performances. This study would be validated, in a future work, by experiments on real platform of tetaneutral.net [19].

A. Simulation Setup

The simulations were performed using the ns-2 simulator modified to support the 802.11n features [16][17]. Different protocol stacks are considered as described in the figure 1:

The network layer is represented by AODV, OLSR and HWMP routing protocols (HWMP is implemented at layer two but is considered here as a routing protocol for organisational reasons). For the MAC layer, we varied the configuration between the mesh architecture based on 802.11s amendement, the MAC part of the 802.11n and the 802.11 standard. Concerning the physical layer, we considered, on the one hand, both 802.11b and Multi-Input Multi-Output (MIMO) [5][10] technology associated to 802.11n standard [9], while varying on the other hand, the propagation models between TwoRayGround, FreeSpace and Shadowing models. For all the scenarios we have used a square topology of 500x500m^2 with randomly deployed static nodes. We varied both the number of nodes (20-40-60-80-100) and the traffic load (10-30-50-70 % of pairs from total number of deployed nodes). We used a constant output (CBR) related to UDP protocol. For the MIMO configuration, nodes are equipped with 2 antennas at both transmitter and receiver (i.e. 2x2 MIMO). We consider both A-MPDU and A-MSDU are enabled. The maximal A-MSDU length is set to 1024 Bytes (i.e two packets of 512 Bytes). Since the initial size of a packet does not exceed 512 Bytes, aggregation then occurs only when the node acts as a router, when it has in its queue at least two packets to the same destination. Data rate is set to 96 Mbps. Using 802.11b physical layer, the bandwidth is set to 2Mbps.

For the 802.11s mesh topology, we assume a network with one MPP set in the network center. Nodes used RANN proactive signalization to get connected to the MPP.

Table1 summarizes the simulation parameters.

B. Simulation Results And Analysis

1) End to End Delay: Figure 2 shows the average end to end delay for the different considered combinations of PHY, MAC and Network layers while increasing the number of deployed nodes and the traffic load in the network. The delay

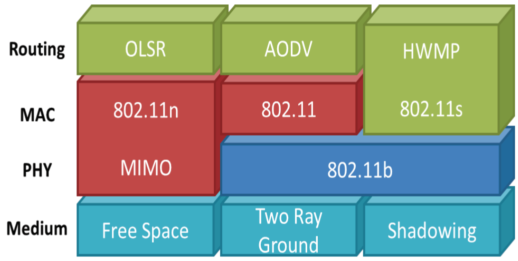


Fig. 1: Protocol Stack.

TABLE I: Simulation Parameters

Paramater	Value
Simulation Time	100s
Topology	500x500m
Number of nodes	20-40-60-80-100
Radio Range	250m
Packet Size	512 Bytes
Packet generation interval	0.005s
OLSR-Hello-interval	2s
OLSR-TC-interval	5s

is expressed in milliseconds and it includes all possible delays caused by buffering, queuing at the interface queue, retransmission delay at the MAC layer, propagation and transfer time.

The results show that, for all possible PHY/MAC/Routing protocol stacks, the end to end delay increases with the network size. This increase is particularly important with HWMP+802.11s. This can be explained from a routing point of view by the hybrid character of HWMP: In fact, on the one hand, delays generated at every Path Request increase naturally with the number of hops. On the other hand, with only one MPP in the network, delays of queuing and buffering may also get higher with the number of nodes in the network.

For small networks, the different considered stacks have the same temporel behavior. However, with larger networks, the pattern begins to distinguish from one combination to another: networks based on routing protocols associated to 802.11n MAC layer and MIMO technology achieved the least delay. This is due essentially to the links capacity and the rate offered by the physical layer. Networks based on the 802.11 and 802.11s generate similar delays with a slight difference relative to the used routing protocol : AODV and HWMP achieved the higher delays compared to OLSR.

The difference between the delay of a light traffic and that of the heavy traffic is none other than the buffering delays which increase with the number of pairs communicating at the same time in the network.

The figure 3 shows more the difference between, on the one hand, reactive and proactive routing protocols and on the other hand, 802.11 and 802.11n MAC layer effects. For OLSR, the average end to end delay increases slightly for the same size except for high network size (100 nodes). In fact, by increasing the number of nodes in the network, the neighborhood changes and the number of hops between source and destination also increases. Thus, delays caused by buffering and queuing delays at intermediate nodes contribute largely in the average end to end delay. Regarding the traffic load, the delay increase is relatively slight. This is because packets are crossing the same path within the same size even when the traffic is getting higher.

The pattern of the average end to end delay is the same for AODV. It grows slightly with the number of nodes for the same reason that the number of hops also increases. However, particularly for AODV the delay increases considerably with the traffic load. This result was expectable since for each new pair of nodes communicating in the network, delays for the route discovery are included. The proactive nature of OLSR allows this protocol to quickly discover the optimal route and then the transmission time of packets takes less time compared to reactive protocols (AODV) which explains the better performance of OLSR in terms of delay. The frame aggregation of the IEEE 802.11n protocol results in a great gain in the end to end delay which is considered very low in all cases compared to delays generated using 802.11 based network.

2) Loss Rate: Figure 4 shows the loss rate. It represents the number of packets discarded among all transmitted packets. The pattern of loss rate is the same for both AODV and OLSR.

We notice that all routing protocols do not perform well under all propagation models when the network conditions become stressful, e.g. heavy congestion. The results also reveal that while the FreeSpace model provides the best performance in terms of packet delivery, the shadowing model achieves the highest loss rates for all routing protocols. The shadowing bad performance is due to the low intensity of the signal caused by possible obstacles. This results in the packet loss on weak links, displays wrongly the links disconnection and leads to the interruption and thus the dire need to set up a new itinerary.

3) Normalized Routing Load: Figure 6 shows the normalized routing load. It reflects the number of routing packets transmitted per data packet delivered at the destination.

We can see from these results the clear and significant increase in the routing overhead generated by HWMP compared to that of AODV and OLSR regardless of the lower layers and the three types of traffic loads. This disparity is due to the hybrid feature of the protocol since it uses the two types of control messages (the proactive and the reactive one). The routing load pattern is the same for all schemes which leads us to conclude that the PHY/MAC have no significant impact on this performance metric.

However, results in the figure 8 reveal some difference according to the routing mechanism. Since the route discovery mechanism of AODV is based of Route REQuest flooding, it follows that the overhead generated by this protocol increases rapidly and significantly with the number of nodes in the network, because, for a given flow between a source and a destination, when the number of intermediate nodes which are diffusing the Route REQuest gets higher, naturally the overhead generated increases. As well, for a higher traffic load across a very large network (100 nodes), AODV generates a peak of routing load.

4) Throughput: The throughput is given in the figure 10. It is expressed in kbits per second and it measures the total number of received packets during the simulation period.

The throughput achieved by the 802.11n based schemes is significantly better than that of 802.11 and 802.11s. This is due essentially to the rate offered by the physical layer. Pattern of throughput within 802.11 and 80.11s based networks is the same as both use the same physical layer which is 802.11b.

When traffic increases, the network throughput relative to the 802.11n increases with the load to consume all the useful throughput. However, the throughput in 802.11/802.11s based networks maintains a certain stability or decreases in some cases.

The results show also that, regardless the load, the throughput for AODV decreases for denser networks. This behavior is characterized as normal because of channel saturation, meaning the resources are limited to the impending demand. For an important traffic, the pattern is the same and throughput remains almost constant on optimal values.

OLSR, however, performs better with higher traffic load. It maintains a good throughput at all cases. The throughput offered by the MIMO technology has a great impact on the general network throughput which is relatively high and suitable for data transfer applications.

IV. Conclusion

In this paper, we studied the impact of PHY/MAC/Routing strategies on the performance of multi-hop wireless mesh networks. We combined the routing protocols (AODV, OLSR and HWMP) with the MAC strategies (802.11, 802.11n and 802.11s) along with different PHY technologies and models (802.11b, MIMO technology, FreeSpace, TwoRayGround and Shadowing propagation models). We found out that, to achieve good performance in the network, all the parts and parameters of the protocol stack must be considered together.

According to the simulation results, we may state that the different propagation models have a considerable impact on the performance of the network. The latter decreases rapidly when the fading models, mainly Shadowing model, have been taken into consideration.

The throughput offered by the MIMO technology has a great impact in the general network throughput which is suitable for data transfer applications. The frame aggregation of the IEEE 802.11n protocol, on the other hand, results in a great gain in the end to end delay which is considered very low in all cases.

Results also revealed that from a routing perspective, there is a notable superiority in the general performance of OLSR, particularly when the network gets denser, although further study of others topologies is needed to validate this conclusion. Some performance results can be explained by the lack of mobility in our topologies. Proactive routing protocols can be less efficient in dynamic networks compared to reactive protocols particularly when talking about overhead and routing load. HWMP is still very sensitive to the network traffic and size, its scalability is not guaranteed and its performance may be affected if the network size is not correctly adjusted.

Based on these observations, our future interest will be oriented to cross-layer proposals and dynamic routing metrics which adapt to the lower layers. Our contributions will be tested as part of the project tetaneutral.net. From a PHY/MAC level, our choice will be IEEE 802.11n protocol in order to take advantage of MIMO technology, the high capacity of the channel and the two proposed aggregation mechanisms. Given the number of nodes in the tetaneutral.net network and the lack of mobility at some nodes, we are interested to OLSR as first choice of the routing protocol.

References

[1] Charles E. Perkins, Elizabeth M. Belding-Royer and Samir Das. *"Ad hoc On-Demand Distance Vector (AODV) Routing"*. Internet Request For Comments RFC 3561, Internet Engineering Task Force, July 2003.

[2] Thomas Clausen and Philippe Jacquet. *"Optimized Link State Routing Protocol (OLSR)"*. Internet Request For Comments RFC 3626, Internet Engineering Task Force, October 2003.

[3] G. R. Hiertz, S. Max, R. Zhao, D. Denteneer, L. Berlemann, *"Principles of IEEE 802.11s"*. IEEE ICCCN'2007, Honolulu, Hawaii, USA, 13-16 August 2007.

[4] 802.11-2012, *"IEEE Standard for Information technology–Telecommunications and information exchange between systems Local and metropolitan area networks–Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications"*.July 2005.

[5] Jianliang Zheng, Yong Liu, Chunhui Zhu, Marcus Wong, Myung Lee. *"IEEE 802.15.5 WPAN Mesh Networks"*. IEEE P802.15-05-0260-00-0005.

[6] Nor Surayati Mohamad Usop, Azizol Abdullah and Ahmad Faisal Amri Abidin. *"Performance Evaluation of AODV, DSDV and DSR Routing Protocol in Grid Environment"*. International Journal of Computer Science and Network Security (IJCSNS), VOL.9 No.7, July 2009.

[7] S. Gowrishankar, T.G. Basavaraju, M. Singh and Subir Kumar Sarkar. *"Performance Analysis of AODV and OLSR in Mobile Ad hoc Networks"*. Proceedings of the 24th South East Asia Regional Computer Conference. Bangkok, Thailand, November 2007.

[8] F. Bertocchi, P. Bergamo and G. Mazzin. *"Performance Comparison of Routing Protocols for Ad hoc Networks"*. Proceedings of IEEE GLOBECOM 2003.

[9] Chih-Yu Wang and Hung-YuWei. *"IEEE 802.11n MAC Enhancement and Performance Evaluation"*. Mobile Netw Appl (2009). Vol. 14. Pages: 760-771.

[10] Jeffrey M. Gilbert, Won-Joon Choi and Qinfang Sun. *"MIMO Technology for advanced Wireless Local Area Networks"*. Proceedings of the 42nd annual Design Automation Conference DAC'05, 2005.

[11] Azzedine Boukerche, Begumhan Turgut,Nevin Aydin, Mohammad Z. Ahmad, Ladislau Blni and Damla Turgut. *"Routing protocols in ad hoc networks: A survey"*. Computer Networks Vol. 55 No. 13. September 2011, Pages 3032-3080.

[12] Michael Bahr. *"Proposed routing for IEEE 802.11s WLAN mesh networks"*. Proceedings of the 2nd annual international workshop on Wireless internet WICON '06. New York, NY, USA 2006.

[13] A. Rhattoy and A. Zatni. *"The impact of propagation environment and traffic load on the performance of routing protocols in Adhoc networks"*.International Journal of Distributed and Parallel Systems (IJDPS) Vol.3, No.1, January 2012.

[14] Stefano Paris, Cristina Nita-Rotaru, Fabio Martignon and Antonio Capone. *"EFW: A cross-layer metric for reliable routing in wireless mesh networks with selfish participants"*. IEEE INFOCOM - INFOCOM , pp. 576-580, 2011.

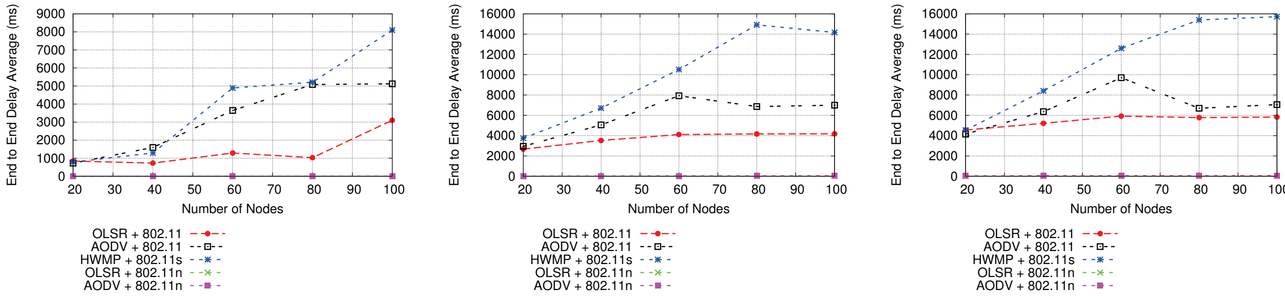
[15] M. Conti, G. Maselli, G. Turi, and S. Giordano. *"Cross-Layering in Mobile Ad Hoc Network Design"*. IEEE Computer Vol. 37, Num. 2, pg 48-51, Feb. 2004.

[16] http://www.isi.edu/nsnam/ns/. Last access : June, 2012.

[17] http://wmnlab.ee.ntu.edu.tw/. Last access : June, 2012.

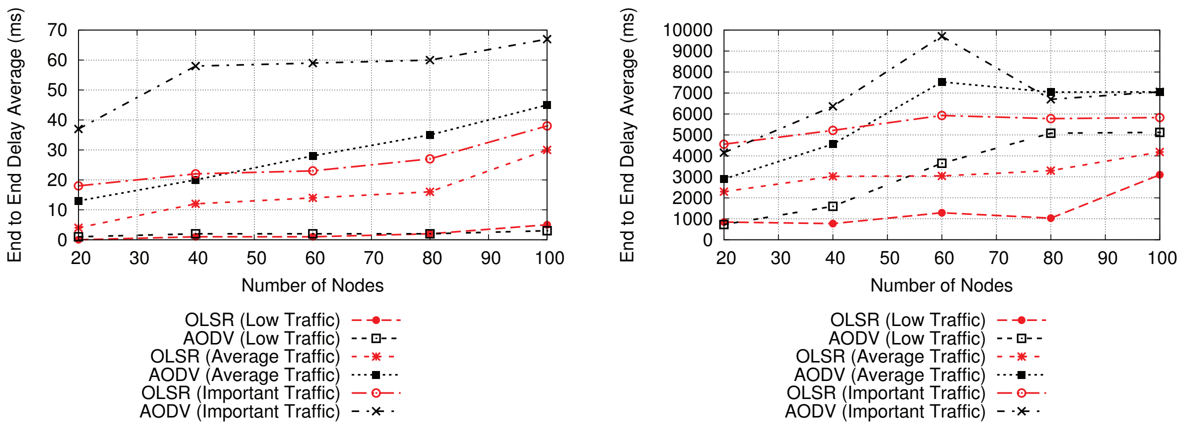
[18] http://fr.wikipedia.org/wiki/IEEE_802.16a/. Last access : June, 2012.

[19] http://tetaneutral.net/



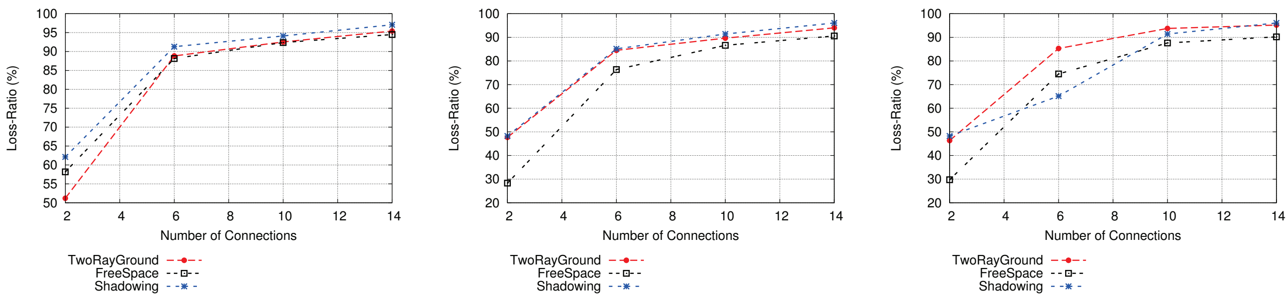
(a) (b) (c)

Fig. 2: End to End Delay by traffic load, (a) Low traffic charge (b) Medium traffic charge (c) High traffic charge.



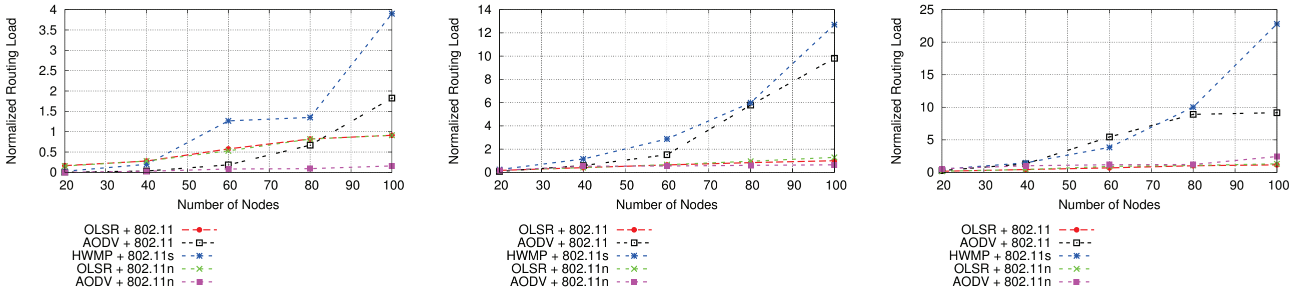
(a) (b)

Fig. 3: End to End Delay by PHY/MAC layers, (a) 802.11n (b) 802.11.



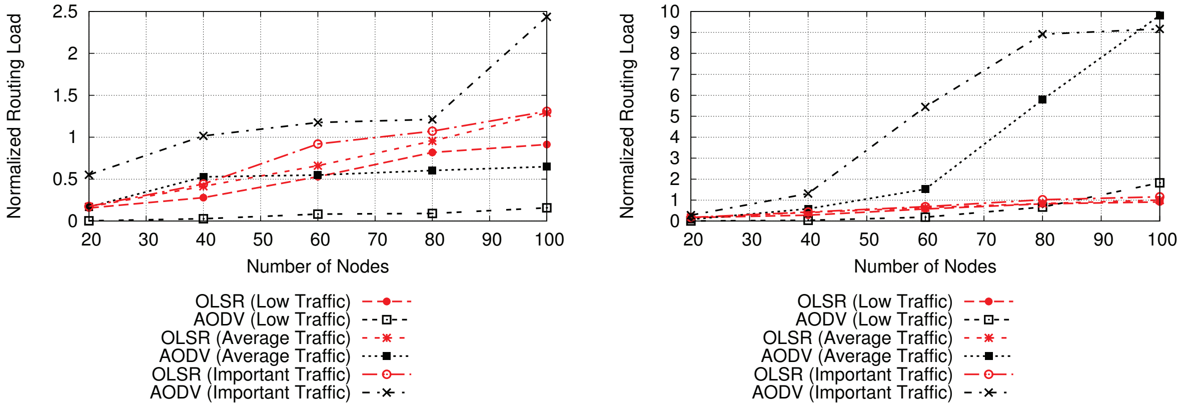
(a) (b) (c)

Fig. 4: Loss Ratio by routing protocols, (a) AODV+802.11 (b) OLSR+802.11 (c) HWMP+802.11s.



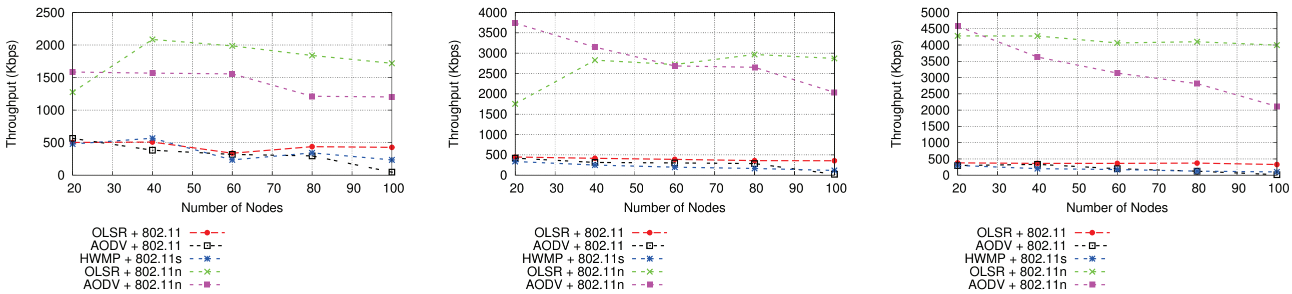
(a) (b) (c)

Fig. 5: Normalized Routing Load by traffic layer, (a) Low traffic charge (b) Medium traffic charge (c) High traffic charge.



(a) (b)

Fig. 6: Normalized Routing Load by PHY/MAC layers, (a) 802.11n (b) 802.11.



(a) (b) (c)

Fig. 7: Throughput by traffic load, (a) Low traffic charge (b) Medium traffic charge (c) High traffic charge.